TIME-GATED IMAGING WITH A SPLIT-BEAM SOURCE

FIELD OF THE INVENTION

This invention relates generally to electromagnetic-based imaging devices and imaging methods. More particularly, this invention relates to time-gated imaging with a split-beam electromagnetic source. One part of a split beam is used for generating an image of an object and another part of the split beam is used for timely capturing the generated image.

BACKGROUND OF THE INVENTION

When X-rays are used to image objects, the X-ray photons are absorbed, scattered, or unscattered as they pass through or are reflected by the object. The unscattered photons ("ballistic photons") acquire spatial modulation, and the difference in flux between the absorbed and the ballistic photons can be detected and used to form an image of the object. The scattered photons, however, degrade the quality of the image produced by increasing noise and thereby reducing the signal-noise-ratio (SNR).

Time-gating is one method of improving the SNR and image quality by reducing the impact of scattered radiation on the object image. The scattered photons (the noise) arrive at a detector (the gate) later than the unscattered photons (the signal) since the scattered photons travel a longer path than the unscattered photons to reach the detector. By turning off the detector before scattered photons arrive, these photons will not be detected and the quality of the detected signal is improved. The speed at which the detector can be switched on and off affects the degree of image improvement. Time-gating also allows the amount of radiation delivered to the object to be reduced without sacrificing image quality. This is particularly advantageous in medical imaging, where the object being imaged is often live tissue.

In addition to time-gating the detector, image quality can be improved by reducing the size of the imaging source. Laser-produced-plasma (LPP) X-ray imaging sources use ultra-short pulse lasers, which generate spot sizes of five to ten microns diameter or less on a target material. The laser pulses can be amplified to energies of hundreds of millijoules at high repetition rates. These narrow laser pulses

produce hard X-ray pulses that emanate from the target material at high power densities of about 10^{22} Watts/cm^2. Such hard X-rays can have energies of 15 to 100 keV or higher, depending on the target material. The source X-rays thus emanate from a much smaller area than a conventional X-ray tube, which typically has a cathode emitting area of nearly a millimeter diameter. The smaller source size produces an image resolution at least 100 times greater than a conventional X-ray tube.

In one such system, X-rays with energies of up to 2MeV were produced from ultra-short pulse driven laser-produced-plasma (LPP). This system utilized an ultra-short pulse laser (0.5 TW, 125 femtosecond, 60 mJ Ti:sapphire laser) focused onto a solid Ta target. First, a low intensity, long duration pre-pulse was used to create a low density plasma in front of the target. Then the main laser pulse was focused to an intensity of > 10^{18} __ onto the target. The main laser pulse accelerated the electrons in the plasma to MeV energies, and Bremsstrahlung X-rays were produced as the result of the electron collision with the target material. The majority of the flux was estimated to be 20 – 150 keV. This is in the range suitable for diagnostic medical imaging. Both the duration of the LPP X-ray source (< 1ps) and its size (< 60 um) are much less than conventional X-ray sources and will allow smaller features to be imaged and different imaging modalities to be employed. These LPP X-ray sources can be optimized at photon energies yielding maximum contrast between normal tissue and cancerous tissue, producing better than 100 micron resolution.

Imaging devices that include LPP X-ray sources and time gates for capturing an object image are known. See, for example the description of such a device by CL Gordon, et al. in "Time-Gated Imaging with an Ultrashort-pulse Laser-Produced-Plasma X-ray Source," 20 *Optics Letters* 1056, 1058 (1995)). However, these prior imaging devices rely on an independently generated high-voltage gating pulse to drive the detector. This arrangement creates difficulty in synchronizing the X-rays with the gating pulse and provides insufficiently fast gating times. For instance, gating pulse widths less than 20 ps are necessary for X-ray photon energies below 40 keV. In addition, the finite propagation time of the electronic gating pulse within the detector results in varying gating times within the detector, and a mismatch of

the photon arrival time and the gating interval. Overcoming these limitations would further improve the SNR and allow smaller amounts of ionizing radiation to be used for imaging.

An objective of the invention, therefore, is to provide an imaging apparatus and a method that are fast, precise, and can synchronize image creation with detection so as to capture a desired image of an object.

SUMMARY OF THE INVENTION

In accordance with the invention, one embodiment of an imaging apparatus includes an electromagnetic pulse source, a beam splitter, an X-ray source, and a time gate. The electromagnetic pulse source generates pulses. The beam splitter splits a pulse into a first portion and a second portion. The X-ray source generates a beam in response to the first pulse portion, the beam directed toward an object for generating an object image. The time gate captures the object image in response to the second pulse portion. A related method apart from the apparatus also performs the steps described above.

In another embodiment of the invention, an imaging apparatus includes an electromagnetic pulse source, a beam splitter, and a microchannel plate detector. The beam splitter splits a pulse into a first portion and a second portion. The first pulse portion is directed toward an object for generating an object image. The microchannel plate captures the object image in response to the second pulse portion. A related method apart from the apparatus also performs the steps described above.

The invention takes advantage of electromagnetically-induced transparency (EIT) to create an optical time gate. EIT is a fundamental property of matter such that excitation by electromagnetic radiation, referred to as "pumping," modifies the absorption coefficient and refractive index of a medium. The invention also takes advantage of photoemissive detectors. Photoemissive detectors have a photoemissive surface ("photocathode") which ejects an electron ("photoelectron") when a photon, such as an X-ray , is incident on the photoemissive surface. The particular photocathode material determines the number of photoelectrons per incident photon ("photoemissive efficiency") and its variation with wavelength.

Almost any material, including common metals, will be photoemissive in response to photons in the X-ray regions of the electromagnetic spectrum. Typically, the most efficient are the alkali halides, alkaline-earth halides, such as MgF_2 and BaF_2, and metal oxides, such as BeO and Al_2O_3.

Photocathodes can eject photoelectrons from the same surface onto which the photon is incident ("opaque" or "reflective" photocathodes), or from the opposite surface ("semitransparent" photocathodes). Opaque photocathodes, for instance full-density CsI deposited on MCPs, are most often used when the incident photons are X-rays. Semitransparent photocathodes usually comprise photocathode material deposited on the rear surface of a transparent window, such as the faceplate of a photomultiplier. Opaque photocathodes usually are windowless because they can be made thick enough to absorb most of the incoming radiation without inhibiting the ejection of photoelectrons.

The invention offers many advantages over the prior art. For example, switching with a short duration pulse allows for a fast time gate. Moreover, utilizing the electromagnetic pulse source to both image and to time-gate allows for easier and more precise synchronization of the time gate with the imaging source. For instance, optically-switching the time gate solves the problem of jitter and inhomogeneous gating. Simplified and direct synchronization of the time gate is accomplished by changing the length of the delay.

These and other features, aspects, and advantages of the present invention will become better understood with reference to the following description, appended claims, and accompanying drawings

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a first embodiment of an imaging apparatus in accordance with the invention.

Fig. 2 illustrates a microchannel plate detector for use in imaging apparatus made in accordance with the invention.

Fig. 3 is a block diagram of a second embodiment of an imaging apparatus.

Fig. 4 illustrates an adjustable delay for use in imaging apparatus made in accordance with the invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The invention can be embodied in a number of ways, several of which are described and shown herein. The same numerals are used for the elements that are common to the different embodiments.

Exemplary Apparatus

A block diagram of a first embodiment of an imaging apparatus 10 in accordance with the invention is shown in Fig. 1. The apparatus includes an electromagnetic pulse source 12 such as a laser that generates a series of well-defined pulses. A pulse from the source 12 strikes a beam splitter 14 that splits the pulse into a first pulse portion 16 and a second pulse portion 18. The first pulse portion is focused through a focusing element 15 and applied to an X-ray source 20. In response, the X-ray source generates an X-ray beam 22. The X-ray beam is directed toward an object 24 such as biological material, non-biological material, and compositions including both biological and non-biological material for which an image is desired. Upon striking the object, the X-rays create an object image comprised of scattered and unscattered photons in the X-ray range. The unscattered photons arrive at a time gate 26 before the scattered photons because of the longer path the scattered photons take. The unscattered photons define a higher quality object image. To capture the unscattered photons and exclude the scattered photons, time gate 26 is turned on when substantially only the unscattered photons are incident upon it. Specifically, the gate 26 turns on briefly in response to the second pulse portion 18 and then turns off, before the arrival of the bulk of the unscattered photons. Synchronizing the gate to the arrival of the unscattered photons that provide the desired image may be accomplished through the use of an adjustable delay 28 through which the second pulse portion 18 travels to reach the time gate 26. The captured image (hereafter the time-gated image 29) may then be viewed by a suitable image viewer 30.

It will be understood by those of skill in the art that the invention as embodied in Fig. 1 can be implemented in a number of ways. Each block does not necessarily represent a separate physical component. The various functions in the blocks may be performed by separate or multiple components, or several functions

may be performed by a single component. Some functions may be omitted in certain embodiments and other functions added in other implementations. For example, the focusing element 15 and/or delay 28 may not be required in all implementations of the apparatus 10.

The specific makeup of the components represented by the blocks of Fig. 1 can vary. The electromagnetic pulse source 12, for example, may be any type of suitable laser such as a Ti:sapphire, Nd:YAG, and Cr:LiSAF laser. Chirped pulse amplification (CPA), which allows short pulse amplification in solid state laser media, can be used to produce the laser pulses. Any laser materials that can generate electromagnetic pulses of about 10 – 30 or even 1-100 femtoseconds duration can be used. The source 12 may comprise a laser pumped by another laser, such as another Ti:sapphire laser, or a Nd:YAG laser, or a laser diode array. The laser outputs about 5 nJ, 10-30 femtosecond pulses at about 800 nm wavelength at a repetition rate of about 250 pulse per second (pps). Repetition rates of 50 – 1000 pps can also be used. The laser can also be operated at wavelengths such as from about 805 nm to about 811 nm, or from about 600 nm to about 1000 nm. A suitable pulse generated by the source 12 may have a width of about 10 – 30 femtoseconds, an energy of at least 125 – 250 mJ, and occur at a rate of about 100 – 250 pulses per second. The initial pulse is stretched to more than 150 picoseconds (ps) prior to amplification. Stretching to about 300 ps is performed by a cylindrical-mirror based expander-compressor system which can expand a 10 femtosecond (fs) pulse by 30,000 and recompress it to within 0.1 fs of its original width. After expansion, the pulse is amplified to about 250mJ in two stages. The first stage is a fourteen pass regenerative amplifier pumped with about 50 mJ of Gaussian-profile 523 nm radiation. At this point the beam is expanded from about 1.5 mm to about 5 mm. The approximately 5 mm beam is then amplified in a four pass arrangement through a 13 mm diameter 13 mm long Ti:sapphire crystal pumped with 850 mJ of 532 nm pump radiation. The resulting approximately 470 mJ pulse is again expanded to 25 mm diameter prior to recompression. Grating diffraction and mirror coating losses in the pulse compressor result in a final compressed energy of about 250 mJ per pulse. The CPA can also be performed such that it results in final compressed energies of about 125 – 250 mJ per pulse, or even up to 1J.

Examples of known components for performing the functions of the other blocks in Fig. 1 include the following. X-ray source 20 may be a laser-produced plasma (LPP) X-ray source. Examples of target materials that can be used as LPP X-ray sources include metals, tantalum, molybdenum, or other material capable of generating X-rays in response to excitation by an electromagnetic pulse source. Time gate 26 may include photoemissive detectors such as MCP detectors and amorphous silicon. Beam splitter 14 may include mirrors that reflect part of a beam of light that falls on it and transmits part. Other devices suitable as a beam splitter are disclosed in *Procedures in Applied Optics* by John Strong (1989). The image viewer 30 may include charge coupled devices (CCD), image plates, or any other device used to image X-rays, such as X-ray film. The CCD can be an ultrahigh resolution CCD (i.e., about 4096 x 4096 pixels), and can be operated in analog readout mode (as in TV cameras) or can directly detect the X-rays. One example of an image plate is a photo-stimulable crystal layer on a plastic substrate, the crystal layer comprising europium-doped barium-fluorohalide compounds. The image plates are exposed to the X-ray image, and scanned, such as with a HeNe laser. Scanning with a laser excites the photo-stimulable layer and releases the energy from the stored image, emitting luminescence light. The emitted light can be detected with a photomultiplier tube. The focusing element 15 may include cylindrical mirrors, parabolic mirrors, and gold-coated aluminum mirrors.

Fig. 2 shows an embodiment of an MCP detector 32, one of the possible choices for time gate 26. An MCP detector can detect electromagnetic radiation that is reflected from or transmitted through an object. An MCP detector uses channel multipliers, a type of multiplier that comprises a single, continuous tube with a photoemissive inner surface, such as semiconducting glass processed to have a high secondary emission. In typical operation, a voltage source 36 is applied along the length of the tube to energize it. A photon entering one end of the tube collides with the inner surface and is multiplied by a secondary emission of photoelectrons that the collision creates. Gains of less than 10^4, from about 10^4 to about 10^7, or greater than 10^7 can be achieved. MCP detector 32 includes a two-dimensional array of channel multipliers 34 in a plate of semiconducting glass. The diameter of each channel multiplier can vary depending on the application. Typical dimensions are 17

nm – 50 nm for smaller channels and up to 1um for larger channels. The spacing between channel multipliers is typically 17 nm to about 20 nm center-to-center spacing for smaller channel and about 5 um - 15 um for larger channels, depending on the diameter of the channels.

MCPs of various channel configurations can be used to multiple the effects of the X-rays. Channel multipliers can be straight or curved, for example, into a "C" or helical shape, and equipped with conical inputs. Alternatively, a "chevron" or "Z" configuration can be used comprising two or more straight-channel MCPs, in series, each operated with less than gains of 10^4, and stacked with their channel axes tilted relative to each other.

The amplified output 38 of a MCP retains the spatial intensity distribution of the input photons 40, and the output of each channel multiplier corresponds to a pixel on the image. Thus, MCPs provide a means of amplifying photoelectrons generated by incident X-ray photons while still maintaining spatial resolution.

To make the MCP detector 32 responsive to the second pulse portion 18, it includes a film of gating material 42 over the top of or in front of the channels in the MCP. The gating material can be any material capable of electromagnetically induced transparency, such as molybdenum and tantalum. The gating material thickness should be thin enough to allow X-rays to propagate through it while in the "on" or transparent state, i.e., when pumped by the second pulse portion 18, yet thick enough to absorb X-rays in the "off" or opaque state, i.e., when not pumped by the second pulse portion. An exemplary thickness range is from 10 nm to 500 nm. The high photon flux provided by the pulse 18 produces an electromagnetically induced transparency in the gating material 42 such that it passes the X-rays 40 carrying the object image while the pulse portion 18 is applied. When the pulse portion is not applied to the gating material, the material absorbs the X-rays. Thus the source 12 through the second pulse portion 18 "switches" the MCP detector 32 on and off in synchrony with generation of the object image via the first pulse portion 16, the X-ray source 20, and object 24. The delay 28 may be added to ensure that the detector 32 is on only when the desired object image is incident on the detector.

A second embodiment of an imaging apparatus in accordance with the invention is shown in Fig. 3. The imaging apparatus 44 therein differs from the apparatus 10 of Fig. 1 in that it employs a Raman amplifier 46, and a Raman generator 48, and a beam combiner 50 in place of the time gate 26. In apparatus 44, the X-ray beam 22 enters Raman generator 48, which contains a Raman material (not shown). In response to the interaction of the Raman material with the X-ray beam, the Raman generator 48 produces an imaging beam 52 that is shifted in wavelength from the wavelength of the X-ray beam 22 by a frequency corresponding to the Raman shift of the material contained in Raman generator 48. This imaging beam 52, which has a Raman-shifted wavelength λ_s, is directed toward the object 24 to be imaged. Photons reflected or transmitted through the object as a result of interaction with the beam 52 and carrying an object image are directed toward the Raman amplifier 46. Meanwhile, the beam combiner 50 receives the second pulse portion 18. It combines the pulse portion with the object image into a combined beam 54 and directs beam 54 toward the Raman amplifier. In response to the presence of the second pulse portion in the combined beam, the amplifier 46 captures the object image accompanying the pulse as a time-gated image 29. The image 29 is then viewable with image viewer 30.

The Raman material in the Raman generator 48 can be a gas, a liquid or even a solid. Typically, a Raman generator is filled with a gas, such as hydrogen or methane, under a predetermined gas pressure. Each different type of Raman material produces a different, associated Raman-shifted wavelength. Depending on the particular needs of the system of FIG. 3, the Raman generator 48 can be a single pass Raman generator, a multiple pass Raman generator cell or a Raman generator-amplifier.

As in apparatus 10, the delay 28 can be adjusted to vary the time of arrival of the second portion 18 and thus the response of Raman amplifier 46 to capture the object image. In the amplifier 46 interaction of the second portion of the pulse 18 with the object image formed from the Stokes-shifted imaging beam 52 causes that instance of the object image that overlaps in time with the second portion of the pulse 18 to be amplified. Any part of the object image that arrives at the Raman

amplifier 46 after the second portion 18 of the pulse 18 is gone is not amplified and does not form part of the time-gated image 29.

In apparatus 44, Raman amplifier 46 is comprised of a cell capable of transmitting both the second pulse portion 18 and the time-gated image 29. It contains a material that produces stimulated Raman amplification of the Stokes-shifted object image when the material is pumped by the second portion of the pulse 18. To have maximum gain in the Raman amplifier 46, the wavelength of the object image produced by the Stokes-shifted imaging beam 52 and the wavelength of the second pulse portion 18 must be separated by the frequency shift of the Raman material in the Raman amplifier 46. The most reliable way to accomplish this is to fill the Raman generator 48 and the Raman amplifier 46 with the same Raman material (and at the same pressure, if that Raman material is a gas) to obtain amplified Stokes signal light from the second pulse portion by way of a Raman interaction in the Raman amplifier 46.

The energy density, or power, in the second pulse portion 18 determines the amplification factor, or gain, of the Raman amplifier 46. A typical gain is of the order of 10^{10}. The gain, in turn, determines the contrast between the amplified time-gated image 29 and the scattered photons that come after. The purpose of the Raman amplifier 46 is to increase the energy in the object image above the energy contained in the scattered photons that follow. As a numerical example, assume that the Raman amplifier 46 has a gain of 10^9 and that the energy in the scattered photons that is transmitted through the object 24 is 10^8 greater than the energy in the object image. Of all of the photons that are transmitted through the object 24, only a very small fraction of such photons, corresponding to 10^{-8} of it (or one part in 10^8), carries the image. Such a low level of photons cannot be seen with the human eye or even with sensitive cameras because it is swamped by the background scattered photons. However, after the time-gated image 29 passes through the Raman amplifier 46, it is amplified by 10^9 while the background scattered photons are not amplified. As a result, the time-gated image 29 that appears at the output of the Raman amplifier 46 has ten times the energy of the scattered photons.

Examples of beam combiners 50 that can be used in apparatus 44 include pellicle beam combiners, including pellicle beam combiners made of nitro cellulose,

mylar, or glass, and pellicle beam combiners manufactured by the National Photocolor Corporation.

Fig. 4 shows one embodiment of delay 28 suitable for imaging apparatus made in accordance with the invention. The delay allows precise synchronization of the arrival of the second pulse portion 18 and the unscattered photons at the time gate 26, whether it is a Raman amplifier 46 an MCP detector 26, or another suitable gate. The delay 28 includes mirrors 80 and 82 and a prism 84 that can be moved as indicated by double arrows 86. The second pulse portion 18 enters delay 28, is reflected from mirror 80 into a delay line 88, through prism 84, off mirror 82 and out of the delay.

The prism 84 is mounted on a movable stage (not shown) coupled to a translator such as a screw or an electric motor. The translator causes the stage to the prism toward (away from) the mirrors 80 and 82 to shorten (lengthen) the length of the delay line 88. By adjusting the delay line in this manner, the distance the pulse portion 18 must travel is increased or decreased and thus the time to reach the time gate 26 is increased or decreased. As described above, delay 28 enables the arrival of the second pulse portion at the time gate 26 to be synchronized with the arrival of the unscattered X-rays. Only the X-rays that are present at the time gate simultaneously with the presence of the second pulse portion are thus detected and form the time-gated image 29.

Applications

Example 1: Medical Imaging

One application of the invention is medical imaging. In imaging for tumor detection, such as in mammography, the increased SNR and increased image resolution provided by the invention enables smaller tumors to be detected. In conditions for which the conventional SNR and resolution are adequate, time-gated imaging allows the dose of radiation to which a patient is exposed to be reduced. Evidence indicates that apparatus made in accordance with the invention reduce the noise by a factor of at least five to ten. This enables the signal strength of the laser pulse to be lowered by a factor of five to ten while still maintaining the conventional SNR and probability for detecting a tumor. For example, a target such as

molybdenum can be used to generate X-rays with about 17KeV of energy. A laser is operated at about 250 pulses per second to allow for about one second exposures, the time that patients can generally remain motionless.

Example 2: Stereo Images

It is possible to split the first portion 16 of the pulse source into third and fourth portions and thereby generate multiple imaging beams to create stereo object images. The third and fourth pulse portions each strike a separate target. The two targets generate separate imaging beams that are directed toward the object to be imaged. An image is formed by photons from the two imaging beams interacting with the object to be imaged. The two targets can be of the same material to generate similar X-ray beams. Two different targets can be used to generate different X-ray wavelengths for subtraction radiography. These procedures can add another dimension of tumor information, and can be used with contrast to further enhance the image.

Example 3: Depth Selection

By detecting reflected X-rays and switching MCP detector 32 on and off, the depth in the object imaged can be selected. Not only is optical switching of the MCP detector a more precise and direct way of synchronizing the imaging X-rays with the detector, it is possible to use computer image management to extract more information. For instance, by controlling the on and off time of the detector, the depth of returned X-ray images is controlled because only X-rays from the depth desired are detected. Using a computer to store images, it becomes unnecessary to move through a material and subtract the image from various layers of material to obtain a clear image.

Example 4:Differential Imaging

Differential imaging is an imaging enhancement technique that includes taking multiple images under different conditions and comparing the images to each other. Differential imaging enhances small variations between the images by suppressing information that remains the same. Any differential imaging technique

can be used in the present invention, including, but not limited to, subtraction or division of one image by another. For example, subtraction radiography can be performed by taking images before and after administering a contrast agent, and storing the images digitally, such as in a computer. Images are taken using X-ray photon energies above and below the absorption edge of the contrast agent. Digital subtraction techniques are used to subtract corresponding pixel values in the images.

Example 5:Computed Tomography

All of the techniques used to perform computed tomography (CT) scans with conventional X-ray sources can be used with the invention. For instance, CT images can be generated using a laser, a target, and a MCP detector. The object to be imaged can be a patient. The patient is situated between the target and the MCP detector. One or more laser pulses is split by a beam splitter. The first portion is focused on the target, and swept in a linear motion across the target. The target generates an imaging beam of X-rays that is emitted in a similar linear motion across the patient. The time-gated image 29 comprises X-rays that have interacted with the patient and captured by MCP detector 32.

The target and MCP detector are then rotated around the isocenter of the plane being imaged, typically by 1 degree, and another time-gated image is obtained. This is repeated until the source and the detector have been rotated 180 degrees. To obtain a cross-sectional image at a different position on the patient, the patient can be moved in relation to the X-ray source and detector.

The time-gated images are processed, for example by a computer, to generate one or more tomographic images. Any of the image processing and image reconstruction techniques and algorithms used in conventional CT scanning, such as convolution-back projection, can be used in the present invention.

CT images can also be generated using a laser, a semicircular target, and a stationary circular MCP detector. The patient is situated inside of the circular MCP detector. One or more laser pulses are split by a beam splitter into a first portion and a second portion. The first portion is focused on and swept across the semicircular target, producing a rotating imaging beam of X-rays. The rotating imaging beam is directed toward the patient. The image comprises X-rays that have interacted with

the patient. The image arrives at the MCP detector, which captures the image when the second pulse portion 18 is present at the MCP detector.

To obtain images at other positions on the patient, the patient can be moved in relation to the X-ray source and detector, for instance, by moving the platform on which the patient is lying.

The time-gated images are processed by a computer to generate one or more tomographic images. Any of the image processing and image reconstruction techniques and algorithms used in conventional CT scanning, such as convolution-back projection, can be used in the present invention.

CT images can also be generated using spiral or helical scanning systems. The spiral scanning system comprises a laser, a target and a stationary circular MCP detector. The patient is situated inside of the circular MCP detector on a linearly translatable platform. The laser and the target are coupled to each other, forming a laser-target assembly, and rotated around the patient while the patient is translated through the circular MCP detector.

Having illustrated and described the principles of the invention in an exemplary embodiment, it should be apparent to those skilled in the art that the illustrative embodiment can be modified in arrangement and detail without departing from such principles. For instance, all the CT techniques can be used with the Raman generator/Raman amplifier embodiment. Types of electromagnetic pulse sources that can be used in the present invention include, but are not limited to, a laser, a laser-produced-plasma X-ray source, such as a molybdenum target.. The present invention can be used to diagnose or treat conditions of the breast. One way to diagnose conditions of the breast comprises pattern recognition, such as visual pattern recognition or computer pattern recognition. One way to accomplish visual pattern recognition comprises viewing the image, and visually detecting abnormal patterns, such as micro-calcifications or tumors. Abnormal patterns can be detected by any pattern recognition method, including computer pattern recognition, such as using a computer and a pattern recognition algorithm to detect abnormal patterns. Computer pattern recognition can be used alone or in combination with visual pattern recognition.

In view of the many possible embodiments to which the principles of the invention may be applied, it should be understood that the illustrative embodiments are intended only to teach these principles and are not intended to limit the scope of the invention. For example, delay may be added at various points in the embodiments and not simply after beam splitter 14. We therefore claim as our invention all that comes within the scope and spirit of the following claims and their equivalents.